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Research Order #1
Phase I - Final Study Phase Report

23 August 1954

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FINAL REPORT

ON PHASE I,

STUDY PHASE

OF RESEARCH ORDER #1

CONFIDENTIAL

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Contractor holds and is licensed under many thousands of patents and patent applications, and it is impractical for this reason to identify those which may be pertinent to this project. It is quite possible that many of them are.

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A. INTRODUCTION

This report covers the work done on phase 1 of the project. Results of all theoretical and experimental work are summarized, and comparative results given. Curves, sketches, and data are given where pertinent to help explain the conclusions reached as a result of our investigations in the study phase of the project.

Basically, the whole system must consist of the following main components:

1. Source of Radiant Energy
2. Detector
3. Modulator
4. Electronics System
5. Optical System
6. Power System.

In addition to discussing the work done on the above physical components of the equipment, we are including a discussion of the general problem of Find, or the establishing of contact between the two operators. This follows the discussion on Power Systems.

The following factors are important and have been kept in mind during our investigations.

1. Maximum overall weight - not to exceed 18 pounds
2. Size of carrying case not to exceed 12 inches x 18 inches x 8 inches
3. Six mile range (night time operation)

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4. Maximum daytime operating capabilities

5. Maximum find time of 5 minutes

6. Simplicity of operation

7. Design, materials used, construction to conform to best commercial practices.

B. DISCUSSION

1. SOURCES OF RADIANT ENERGY

The following sources of radiant energy were investigated.

a. Cesium Arc Lamps

b. Xenon Arc Lamps

c. Zirconium Arc Lamp

d. Tungsten Incandescent Lamp.

a. The Cesium Arc Lamp

This lamp is widely used in infrared communications. It has several favorable factors among which are the following:

1. High intensity infrared radiation.

2. Suitable for wide beam operation.

3. Easily modulated by straight-forward electronic means.

The disadvantages, particularly unfavorable to light-weight, portable equipment are:

1. Most of the energy of the radiation is in the very near infrared, making it difficult to achieve good visual security.

2. Due to source size it requires a large objective, making a compact optical system impossible for narrow beam transmission.

3. A considerable amount of power is required to operate the lamp.

4. Weight of the components, necessary for the modulating system, would represent about 30% of the total weight of the equipment.

It was apparent after the above advantages and disadvantages were weighed that the cesium lamp would be unsuitable for our system.

b. <u>Xenon Arc Lamp</u>

This lamp has the following favorable factors:

1. Small arc size (approximately 3 mm x 0.48 mm for one type)

2. Intense radiation in the infrared region (approximately 38% between 0.75 microns and 2.0 microns)

3. Spectral distribution apparently matches reasonably well the spectral response of the lead sulfide cell. More consideration will be given to this matter in the discussion under detectors.

The disadvantages of the Xenon arc lamp are:

1. The considerable amount of power required to ballast the lamp

2. The weight of equipment necessary for modulating the lamp which is about 30% of total allowable weight of entire equipment
3. The requirement of a high voltage Tesla type coil for starting
4. The difficulty of restarting when the lamp is extinguished
5. The requirement for rigorously limiting the modulation percentage to 75%.

The small source size and apparent brightness of the Xenon arc were so attractive that we felt justified in further pursuing the possibilities of a Xenon source.

We decided to develop a system for electronically modulating the Xenon lamp.

The following considerations were important:

1. Minimize ballasting power required
2. Maintain component size and weight as low as possible
3. Develop simple and positive system for establishing the arc discharge
4. Obtain a percentage of modulation as high as possible, approximately 75%.

This system was developed and range tests were conducted, using our Vacuum Range Optical Attenuator. An extensive discussion of this system will be found in the following pages under Modulators.

For future reference, the spectral energy distribution of an Xenon lamp is shown by the curve, Figure 1 in Appendix I.

Unfortunately, a curve of the particular lamp (a 50-watt lamp) was not available. However, curves of a 150-watt lamp are available, and it is this curve that is shown in Figure 1 referred to in the previous paragraph. While the intensity from the 150 watt lamp is much greater (watts/micron) than for the one used, the spectral energy distribution would generally be the same.

It is noted that the Xenon lamp has high energy radiation in the range from .8 microns to and including 1.3 microns. This represents high intensity radiation in the near infrared region, a region in which we are much interested as will be discussed in the following section under Detectors.

c. Zirconium Arc Lamp

The Zirconium arc has the following advantages:

1. Intense brightness (4040 Candle/cm^2 for a 25-watt lamp)

2. Long life (800 hours)

3. Small source size, .029 in. diameter, is favorable for narrow beam communications, once the target has been located.

Among the disadvantages are the following:

1. Power required for ballasting the lamp

2. Weight of modulating equipment

3. The extremely small source size, which is favorable, once communication is established, but is unfavorable for finding the detector due to the narrow beam angle.

Our conclusion was that especially factor (3) above outweighed all advantages previously stated. Therefore, we did not give the Zirconium Arc Lamp further consideration for use in this system.

d. Tungsten Incandescent Lamp

The Tungsten lamp has the following desirable characteristics:

1. Good brightness, although not as high as Zirconium, (2100 Candle/cm^2).

2. Good intensity of radiation in the infrared range from 0. 9u to 5u and beyond

3. No problem in starting because the lamp is merely turned on by an ordinary switch

4. No size and weight problems since modulation of the lamp can be achieved by a small mechanical modulator.

5. Small source size (7 mm x 1 mm for narrow beam communication) but not so small that a larger beam width cannot be formed by simple adjustment of the optical system for locating the target.

6. Small power requirements for operating the lamp (30 watts). This is a very important consideration in our particular system. Note that all this power is consumed in the lamp itself, no ballast being required.

Among the disadvantages are the following:

1. The Tungsten source is not as bright as some of the sources previously discussed.

2. The life is relatively short, 30 hours, at the filament temperatures which are being considered (approximately $3200^{o}K$).

It was decided to develop a system to mechanically modulate the Tungsten lamp. The success of such a system depended largely on a satisfactory modulator. Such a modulator was satisfactorily developed for this application.

The above system is further discussed in the following pages under the Section on Modulators.

Figure 2, Appendix I, shows a curve of spectral transmission for a Tungsten lamp. This curve will be discussed in detail in the following section on Detectors.

2. DETECTORS

The following detectors were considered:

a. Silicon Cell

b. Thalofide Cell

c. Lead Selenide Cell

d. Lead Sulfide Cell

e. Photomultiplier Tube.

Detectors are discussed in the monthly reports of 3 May 1954 and 3 June 1954. These results are here summarized. The lead sulfide cell, which is the cell we have chosen to use, is further discussed.

a. Silicon Cell

This cell has the following favorable characteristics:

1. Good frequency response in the audio range.
2. Relative insensitivity to background light.

The disadvantages of the cell are:

1. A rather low signal to noise ratio
2. The existence of major peaks in the near infrared (0.85 microns), close to the visible, which limit visual security to a very great degree
3. The unavailability, to our knowledge, of commercial sources of a satisfactory nature.

b. Thalofide Cell

This cell has the following favorable characteristics:

1. High signal to noise ratio

2. High sensitivity.

The main drawbacks to the use of the cell are:

1. It is seriously affected by background light

2. Its spectral response cuts off at 1.3 microns, the peak occuring at 0.9 microns. For this reason it is not a good match for tungsten or other black-body sources

3. The size of its sensitive area is large in commercially available types.

c. Lead Selenide Cell

The information we have is that it has been difficult, if not impossible, to prepare lead selenide cells of uniform sensitivities.

A reliable commercial source is not known to us at the present time.

d. Lead Sulfide Cell

The lead sulfide cell has the following favorable characteristics:

1. The response is almost uniform in the infrared, peaking slightly at approximately 2.5 microns with a cut-off near 3.5 microns. It is useful down to and below 1 micron

2. The response is high compared with most other cells.

3. Its output is linear over a great range of luminous flux, which means it is not affected seriously by background, at least not to the extent that most other detectors are affected.

4. The art of manufacturing these cells is well known, and they are readily available in various sizes from reliable sources.

One problem in using the cell is the fact that its sensitivity varies with ambient temperature. However, this is not considered serious for our application.

Figure 3, Appendix I, shows the spectral response characteristics of the lead sulfide cell. A comparison of this curve with those of Figures 1 and 2, Appendix I, show the lead sulfide cell to have good response in the range of spectral transmission for both the Xenon and tungsten sources. It is therefore, a reasonably good match for either source, or putting it another way about as good a match as we can attain.

The lead sulfide cell was used in two experimental systems, one with a Xenon source, and the other with a tungsten source. The Xenon source was electronically modulated, and the tungsten source was mechanically modulated. Excellent results were obtained with both, as discussed in the following section under Modulators.

3. MODULATORS

Broadly speaking the choice of modulation schemes for use in an Infrared communicator must be one of the following two types:

a. Electronically Modulated Arc System

b. Mechanically Modulated Arc or Filament System.

The modulating systems which we have chosen to consider will be discussed in the following order:

a. Electronically Modulated Xenon Arc System

b. Mechanically Modulated Tungsten Filament System.

a. Electronically Modulated Xenon Arc System

This system requires the following components (reference is made to Figure 5, Appendix II for the circuit sketch, and to the data given in Table I, Appendix III):

1. Power transformer. (T_1)
2. Rectifier
3. Filtering condenser (C_1)
4. Modulating Transformer (T_2)
5. Ballasting resistance (R_1)
6. Radio frequency choke coil (RFC)
7. Xenon arc lamp
8. Electronic modulator tube
9. Tesla coil or equivalent for starting the arc discharge (starting circuit)
10. D.C. ammeter.

Briefly, the functioning of the system is as follows: a filtered output voltage of approximately 80 volts DC appears across the electrodes of the lamp. An arc will not be started at this potential. Therefore the high voltage of a Tesla coil is applied to the positive electrode of the arc lamp for starting.

Immediately upon the formation of the arc the potential across the electrodes drops to approximately 25 volts. A ballasting resistor of 10 ohms is necessary to maintain the arc. The current through the lamp is approximately 1.25 amperes. This, of course, means that approximately 17 watts is dissipated in the ballast resistor.

All told, approximately 70 watts of power is used, of which 35 watts is utilized in the lamp. Rectifier and other system losses account for the balance.

A single 6AQ-5 tube is used to current modulate the lamp through a transformer as shown in Figure 4, Appendix III. Modulation percentages of 75% were obtained without extinguishing the arc. However, the following unfavorable results were obtained:

1. Not all lamps would stand 75% modulation, i.e., some would extinguish at a lower percentage modulation.

2. The power requirements (70 watts) proved to be high.

3. While a lamp could always be started some difficulty was occasionally experienced in starting, several attempts being necessary at times.

4. The arc did not always form in the same place when starting, thus presenting a problem in optics.

5. The total weight of the system is approximately 4 pounds, which is quite high considering our weight limits on the equipment.

A range test was made using our optical attenuator, and a range equivalent to five miles (Average Clear Weather) was obtained. As will be discussed later, this range was exceeded by the mechanical modulation system and Tungsten source.

Figure 6, Appendix II, shows the system used in the experiment.

A twenty-watt, high fidelity amplifier was used to modulate the Xenon arc lamp. A Tesla coil was used for starting. The optics consisted of merely a 4-inch diameter plastic Fresnel lens, and a standard infrared filter.

The detector system consisted of a lead sulfide cell, and a 4-3/4 inch diameter parabolic mirror for focusing radiant energy on the cell.

A second twenty-watt high fidelity amplifier was used for the receiver.

Good intelligibility was obtained over the range of five ACW miles, from phonograph records of speech.

An audio oscillator was used to measure frequency response over a range of 300 to 3000 cycles. Reference is made to Table 2, Appendix III giving the data obtained from the measurements. As indicated from the data, the ratio of receiver voltage output at 300 cycles to that at 3000 cycles is approximately 16:1 which is poor frequency response.

b. Mechanically Modulated Tungsten Filament System

I. General Problems Involved:

Several systems of mechanical modulation have been considered. A satisfactory mechanical modulator must possess the following features:

1. A high natural frequency of 1500 cycles or greater
2. A flat response over a wide range of frequencies
3. Proper damping to avoid over-shoot and instability.
4. High sensitivity, to minimize power requirements.
5. Great ruggedness, with a minimum of adjustment required.

The basic problems involved are the same for all mechanical systems, whether translatory or torsional.

In order to obtain a high response, the natural frequency must be high. This means that the mass or inertia, as the case may be, of the moving system must be as low as possible. On the other hand linear response over a wide range of frequencies requires certain definite relationships among the following: Mass or Inertia, Damping and Compliance.

Damping must be sufficient to avoid overshoot or instability, i.e. hunting. However, too much damping will deaden the system; i.e., increasing the time constant and slowing the system response gives a large transient error and a poor frequency characteristic.

Where power requirements are a consideration, the mass or inertia of the system must be kept low. Theoretically great response can be obtained for systems of large mass or inertia, provided sufficient power is available and can be put into the system. However, in a small compact unit such as the one under consideration large power is not available, and if it were it could not be utilized in the galvanometer system.

II. Torsional Systems (Galvanometer)

This system was used in our experimental work for modulating the Tungsten filament source. Table 2, Appendix III, gives the data for the particular galvanometer used in our experimental work. Figure 4,

Appendix I shows the deflection (response vs. frequency) of this galvanometer.

Reference is made to Figure 7, Appendix II, which shows an experimental system for range testing a mechanically modulated Tungsten Lamp source. This system uses a galvanometer with a deflection, approximately linear, of $\pm 16^{\circ}$. Two condenser lenses and a projection lens, along with a filter make up the optical system. Except for the modulating method and the optical systems, the arrangement of the system for range tests was substantially the same as that used for the range test of the Xenon Arc System. This system however gave an Average Clear Weather range of at least seven miles compared with the five miles previously reported for the Xenon system.

The mechanically modulated tungsten lamp has the following excellent features:

1. The total power requirements are low. (The lamp and modulator together require only 32 watts of which 30 watts are available to the lamp).
2. This method of modulation uses 100% of the light, and 100% modulation of the lamp source is obtained.
3. The modulator is light in weight, the total modulator weight being one pound for the experimental unit.

4. The modulator is small, compact, and rugged.

5. Reasonably good intelligence is obtained over a seven mile range of communication.

III. Other Mechanical Systems

1. The Type W Vibrating Mirror System.

In this system, a vibrating mirror modulates radiation from a tungsten filament lamp. The radiation is focused by a gold plated elliptical mirror onto the vibrating mirror.

A second grid mirror, is placed between the elliptical mirror, and the vibrating mirror. This second mirror is coated with reflecting strips of gold, alternated with clear spaces of the same width. Consequently, this system uses 50% of the light, as compared to the 100% used in the system previously discussed.

As the modulating mirror moves back and forth, light is reflected from the grid surfaces, and is collimated at the same time. Thus the movement of the vibrating mirror modulates the light source.

The main disadvantages of this system are:

(a) It is difficult to adjust and keep adjusted

(b) It lacks ruggedness

(c) It utilizes only 50% of light

(d) The maximum range reported is about 3 miles.

The system has the following advantages:

(a) It operates on very small amounts of power

(b) It is easy to get power into, since its coils are stationary and increased coil size does not increase inertia as in the torsional system.

This system was rejected because of the disadvantages previously mentioned.

2. <u>The Translatory System</u>

This method would use two grids, one in front of the other, with openings of the same size, the openings in each grid being equal in size to the grids themselves.

One grid would move in front of the other, thereby blocking out the radiation. Again only 50% of the light would be used, and we have the same disadvantages that are experienced in the type W system.

An effort was made to use 100% of the light and modulate 100%. However, with the size of the moving mass, and distance of motion required, the power for operation would be prohibitive in this system.

3. Array of Wires Parallel in a Magnetic Field

This system would use parallel wires, placed perpendicular to and in a magnetic field. The displacement of the wires would be proportional to the current they carry. A varying current causing motion of the wires modulates the light passing through a grid structure.

However, this method utilizes only 50% of the light, compared with the 100% used in the torsional (galvanometer) system, and would require more power.

4. The German Lightsprecher System

There are no grids of any kind in this system. Light undergoing total internal reflection in a large prism is modulated by the mechanical movement of a much smaller prism. The movement of this prism is exceedingly small thus requiring very little power for operation.

The system is most remarkable in both design and functioning. However, it was not considered advisable to use this system for the following reasons.

(a) Very extensive problems are involved in optical design.

(b) Very great precision is required in the optical system.

(c) The mechanical modulator would be one of special design.

In reviewing the mechanical systems which have been discussed, it can be said that the torsional (galvanometer) system requires less development time because modified galvanometers can be readily obtained; whereas the other systems would require almost complete development of the mechanical modulators. Also performance of the galvanometer system is comparable to the best of the other systems, and better than the majority, the one notable exception perhaps being the Lightsprecher System, which would be a major development in itself requiring a considerable amount of time.

4. ELECTRONIC SYSTEM

Work has been started on the characteristics and design of the necessary electronic amplifiers. These amplifiers or circuits must perform the four functions of the following gear at different times:

a. Audio oscillator and power amplifier for single frequency transmission

b. Tuned amplifier for use in the receiver when reception is of a single frequency audio tone.

c. Voltage and power speech amplifier with suitable characteristics for modulating the transmitted beam

d. Voltage amplifier with suitable characteristics for use in the receiver in voice communication.

At the present it appears possible to use the same basic amplifier for all of these functions and to provide the necessary circuit modifications by switching.

Preliminary to the design of the two audio amplifiers, an examination was made of the effect of various system frequency responses on intelligibility. These tests were made under essentially noise free conditions and were designed only to indicate a preference for either the standard 300-3000 cycle response or a response which rises steadily from a 300-600 cycle low frequency cutoff. The test equipment consisted of a Shure 505B microphone, a Golden Knight amplifier, an RC coupling circuit which could be switched to provide either essentially flat coupling or a large degree of under coupling (to give the rising response characteristic), a Kron Hite variable Band Pass, and Navy CCN49505-A earphones. It was the unanimous opinion of the eight people who took part in the qualitative test that the rising characteristic gave greater intelligibility than the 300-3000 cycle system when the voltage gain of the two systems was equal at 1000 cycles, both at threshold bearing levels and at moderate levels.

As a result of these tests a preliminary amplifier design was made making use of insufficient RC coupling between all stages. The use of unbypassed cathode bias resistors was discarded on the basis of too much loss of gain for the small resulting tilt in the response. The resulting amplifier uses a 12AX7 and a 6AQ5. In final design it is likely that subminiature tubes will be used for the voltage amplifiers.

If batteries are used the tubes will be of the filamentary type because of the power saving. If the 800-cycle alternator provides primary power, cathode type tubes will be necessary.

In the transmit voice position the amplifier rises 6 db per octave and provides 75 db gain at 1000 cycles. This gain is more than necessary to over-modulate the galvanometer.

In the transmit-find position, the microphone transformer is disconnected and the first triode amplifier is converted to a phase shift oscillator. The second triode amplifier and the power amplifier are unaltered. The frequency of oscillation is pre-determined since fixed resistors and capacitors are used. The frequency will be in the range 1000-2000 cycles.

In the receive-voice position the 75db voltage gain of the amplifier is increased another 12db by virtue of the higher impedance of the earphones as compared to the galvanometer. This is still insufficient and a preamplifier, used only when receiving, is necessary. The additional gain needed is of the order of 20db.

The desirability of the rising characteristic being used in the receiver was examined. In this test a galvanometer modulated beam was received after vacuum range attenuation. The transmitter amplifier was as described above. Instead of direct input from the microphone a Golden Knight amplifier was used to provide further shaping of the response characteristic. In practice it was found that a 12db rise per octave in the transmitter instead of the 6 provided by the transmitter amplifier described above gave a further increase in intelligibility.

The receiver amplifier was a Golden Knight with a Kron Hite variable bandpass. At extreme range the rising characteristic at the receiver also seemed to contribute increased intelligibility, however, a large number of observers were not available, and this finding is therefore still questionable.

In the receive-find position a narrow pass filter or tuned amplifier is being considered. The decrease in bandwidth during this function should lead to increased signal to noise ratio at a given range.

5. OPTICAL SYSTEMS

The optical systems studied have in all cases been dictated mainly by modulator requirements, keeping in mind always the desirability for a maximum beam width with the small sources being considered. The greater flexibility in detector design, i.e., size and shape, has allowed the modulator requirements to be the prime factors.

The beam width of the transmitter is determined by the source size and objective focal length, being inversely proportional to the latter and directly proportional to the former. Since the available power limits the source size to approximately 7 mm x 1 mm for either tungsten or Xenon sources, the beam width will pretty well be determined only by the focal length.

On the other hand, the vacuum range of the system is dependent on the aperture of the objective. Thus, given a certain brightness for the source and a certain aperture for the objective, the resultant vacuum range of the equipment is <u>independent of the beam width.</u> The implication is that if the beam width is changed either by using a larger source (without changing its brightness) or altering the focal length (without changing the aperture) the resultant vacuum range will remain fixed. This assumes perfect optics, of course.

The Xenon source, being electrically modulated, has attached to it no especially limiting optical properties. For example it can be used equally well with reflectors, ordinary lenses, or Fresnel lenses. A deep parabolic reflector is well suited since it offers a short focal length and a large aperture.

In our application, the deepness of the parabolic reflector would be limited by the nature of the detector; for example, using a plane surface detector such as PbS, the maximum relative aperture would be f/0.25.

The mechanical modulating scheme unfortunately is not so versatile. First, the physical dimensions of the galvanometer are such that numerical values of relative aperture cannot drop below f/0.8. This almost immediately eliminates the possibility of any simple lens systems for the objective other than perhaps those employing aspheric surfaces, including Fresnel lenses.

Furthermore, parabolic reflectors were not extensively considered because it was feared the galvanometer and magnet assembly (which must be located at the focus of the objective) would obstruct too much of the clear aperture of the reflector. There is at least one way out of this trouble, however; and it will be described a little later on.

First a description of the mechanical modulating scheme will be given. A real image of the tungsten filament is formed by a condenser lens system on the torsionally suspended mirror of a galvanometer. This image is located at the focus of the objective, and light reflects off the galvanometer mirror into the objective, where it is collimated into the transmitted beam. At rest (zero signal input) the mirror is situated at an angle which allows the reflected light to illuminate half the objective aperture. When a signal is fed into the galvanometer, its angle changes and more or less light enters the objective aperture. Since the real image does not move, the transmitted beam remains fixed in direction. The illumination in the beam is proportional to the amount of light reflected into the objective aperture; in this way modulation is achieved. The galvanometer must necessarily have a high frequency response and this limits the size of its mirror and its sensitivity.

The theoretical limit for the relative aperture of this system is f/0.707. This corresponds to a 45° angle between the objective axes and a ray proceeding from the edge of it. This extreme ray strikes the galvanometer mirror at an angle of 90°, or grazing incidence, when the mirror reflects maximum light into the objective. A little thought reveals that for extreme ray angles greater than 45°, either the galvanometer mirror gets in its own way or the condenser system gets in the way of the objective. A more practical limiting value is f/0.8. This allows for a slight misalignment between the mirror surface and rotational axis.

Only two answers to this optical problem out of several thought up are considered at all practical. Each system requires at least one condenser system and one objective.

The first of these is the simpler in principle in that it requires the minimum number of components; namely a condenser system and an objective. A condenser system has been designed which has a relative aperture of f/.98, and is corrected to a fair degree for spherical abberation. The objective is to be a molded plastic Fresnel lens also corrected for spherical abberation.

The main difficulty with this system so far is that a Fresnel lens of the right characteristics has not been found available. Three suppliers have been contacted without positive results. These are Eastman Kodak, which will not consider special tooling for the small quantity involved; the Hartley Lens Co., which does not have the facilities for anything larger than about 3-1/4 inches, and the Stimsonite division of American Gas Accumulator, which is considering the problem somewhat pessimistically.

A fourth possibility is the Bolsey Lens Company, from which we are now awaiting a reply to our letter.

The second system has already been alluded to, and it uses a parabolic reflector for the objective. In order to remove the galvanometer and magnet assembly from obstructing the aperture, a second condenser system is employed in series with the first. The galvanometer and magnet assembly are then placed between these two. The reflector is then obstructed only by one condenser system with associated supports and perhaps the detector cell.

In this system the obstructed area may run as high as 17% of the total, corresponding to a decrease of 17% in the average brightness of the surface. However, it should be borne in mind that the risers in a Fresnel lens also result in decreased average brightness; and that this effect becomes more pronounced as the distance from the lens center increases. For example, at the edge of an f/0.9 lens, the brightness is only 70% of the maximum (which occurs at center), and the average brightness over the entire surface is approximately 90%. Moreover the plastic material does not transmit infrared without considerable loss. Thus a parabolic surface can be made to compare rather favorably with a Fresnel lens in spite of the necessary obstructions. A further loss in the reflector system is due to the transmission factor of the second condenser; and this can easily amount to 10%.

There are many manufacturers of parabolic reflectors; and they have been made of metal, plastic and glass. The metal ones are made either by spinning or electro deposition onto a master mold. In the latter case they become rather heavy (20-25 oz.) whereas in the former it is difficult to get a good figure. The plastic ones are quite light and can be made very stable dimensionally. In addition, their surface can be very accurately finished. Those made of glass have a rather low impact strength, their weight averages between that of the heavy metal and light plastic ones, and their figure (for the molded ones) lies between the spun metal and cast plastic ones.

From the standpoint of performance the cast plastic ones appear to be the best. Only one supplier is known, and this is the Polaroid Corp. They are at present considering the problem but we do not know whether they want to accept an order. Tooling will be necessary and the resultant cost can be expected to be rather high.

6. POWER SOURCES

The following Power Sources have been considered:

a. Batteries

b. Internal Combustion Engine

c. Reciprocating Steam Engine

d. Steam Turbine

Batteries have the following favorable qualities for the system:

a. They are quiet in operation; this is important for security reasons.

b. No external fuel supply is required.

c. There is no problem involved in starting, such as there is in the case of internal combustion engines.

d. Voltage Regulation is not required.

They have the following disadvantages:

a. They must be quite frequently recharged, when used frequently.

b. They must be recharged after long periods of storage. This would be a disadvantage if quick use of a given equipment were required in an emergency.

c. Batteries are quite heavy, so power available is governed by weight requirements.

Internal Combustion Engines

The internal combustion engine has the following advantages for use in the system:

a. Considerable power is available with small quantities of fuel.

b. The small internal combustion engine is light in weight.

c. Fuel used is easily obtained.

The disadvantages are:

a. The internal combustion engine is noisy. Means must be taken to silence the engine, not only from exhaust and intake but from mechanical engine noise.

b. A rope is the most convenient way of starting this engine. This is not difficult but is a nuisance compared to merely switching on battery power.

c. An external supply of fuel is required.

d. Some regulation of engine speed is required to maintain generator voltage within $\pm 10\%$.

Steam Turbine

The weight of the smallest steam turbine that we were able to locate is about four times the maximum allowable weight for the whole system under consideration. This factor alone is sufficient to drop the steam turbine from further consideration.

Reciprocating Steam Engine

The reciprocating steam engine has the following advantages; among others:

a. It is very quiet in operation

b. Fuel sources would not be a problem.

However, it has many disadvantages:

a. Gearing is necessary to drive the alternator at 12000 r.p.m.

b. Consumption of water is quite great, and a supply of water is necessary. This adds considerable weight.

c. The engine would have to be designed and built, starting from scratch.

In view of the all-around requirements the small internal combustion engine is the most feasible, providing we can satisfactorily silence it. This problem is being worked on at the present time.

In event the engine cannot be sufficiently silenced, the other alternative will be the use of batteries.

Specifications for an engine operating on kerosene have been given McCoy Products. Data and specifications are given in Table 3, Appendix III.

THE PROBLEM OF ESTABLISHING CONTACT

Methods of establishing contact between two units have been considered. Basically all find systems require the use of set patterns of operation by both stations. The complexity of devices and/or procedures for establishing contact is determined by three factors, the uncertainty of location of the other station, the receiver beam width, and the transmitter beam width. The problem becomes more difficult as the first of these quantities becomes large and as the last two become small.

Arbitrarily, a horizontal uncertainty of $\pm 5^{\circ}$ and an elevation uncertainty of $\pm 2^{\circ}$ have been taken as nominal values. With the horizontal uncertainty due only to compass errors and a range of several miles more likely values would be $\pm 2^{o}$ horizontally and $\pm 1^{o}$ vertically. The final system will be a compromise between complexity of design and operation and maximum acceptable degree of uncertainty of location.

All systems for finding can be considered as special cases of a scanning sequence. That is the receiving station will sweep the area of uncertainty in a number of horizontal scans, each displaced vertically from the preceding one by the receiver beam width. Thus the number of horizontal scans is $N = \frac{E}{R_E}$ where E is total elevation uncertainty, 2 to 4 degrees, and R_E is the angular height of the receiver beam.

The picture is further complicated by the fact that even if the receiver were properly oriented he would hear nothing unless the transmitter were also properly oriented. Thus the transmitter must be oriented to each of N positions.

$$(n = \frac{E}{T_E} \frac{H}{T_H}$$

where E and H are the elevation and azimuth angular uncertainties and T_E and T_H are the transmitter elevation and horizontal beam widths) and left there for the period of time required for the receiver to complete one scan. Thus it can be seen that if the time for one horizontal line scan of the receiver is 2 seconds, the time required for establishing contact could be 2Nn seconds.

An experimental determination of this scanning system was made where the uncertainty was 10° in both elevation and azimuth. The transmitter was properly aligned and the receiver then had only to make a single complete scan of the area of uncertainty. The receiver beam was $1/3^{\circ} \times 1/3^{\circ}$ and the average time of find was 100 seconds in 35 trials. This figure is of the same order of magnitude as predicted with the 2 second per scan assumption i.e., $2 \times \frac{10}{1/3} = 60$ sec.

On this basis with a transmitter beam width 1/6 the area of uncertainty, contact would be established in about 10 minutes.

One result of the experimental determination of find time was the obvious need for some mechanical means for aiding in the establishment of the vertical increments between horizontal scans. Two such devices may be considered as representative. The first consists of a stack of plates from which one is automatically removed with each horizontal scan. This stack is then used to determine the elevation setting. As an example of extreme simplicity a pin could be caused to ride in a channel striking either the upper or lower surface. This system provides only a two line field, hence the receiver elevation beam angle would have to be equal to half the angular uncertainty.

The other approaches to solution of this problem involve use of beam dimensions during the find time that are much larger than those used for communication.

The receiver beam width can be increased only by increasing the area of the detector or reducing the focal length of the lens.

Since the latter course is not practical only the change of cell size has been considered. The final decision as to whether this will be done will have to await field tests since such an increase will reduce the signal to noise ratio at a given range. That is the final decision will be one of extending the range at the expense of find time.

The last variables in the equations are the transmitter beam dimensions. These may be increased by increasing the size of the source by defocusing or again by changing the focal length. The last method is impractical as it was for the receiver. The first method is difficult to achieve if the galvanometer is maintained as the modulating means. This is because the effective source size is limited by the galvanometer mirror.

Consideration has been given to the use of a chopper for modulation and a filament of increased size. Since the galvanometer mirror would now form the limit, a special galvanometer with a fixed mirror has been sought and a quotation for its construction received. In general this system is to be used only as a last resort.

By far the most promising method of increasing the transmitter beam width is by defocusing. By this means the beam width can be increased nearly any amount with a corresponding loss of range. However, this loss is in the range of detection of a single frequency audio note. The range for detection of a single frequency signal greatly exceeds the range over which voice communication is possible, especially when suitable electronic filters are used. The ideal situation is then achieved when the beam width during find is increased to the point where the range for a single tone is just equal to the range for voice communication with a properly focused beam.

C. CONCLUSIONS AND RECOMMENDATIONS

On the basis of our theoretical study and experimental work it is our recommendation that we be allowed to proceed into the developmental phase of this task.

The equipment to be developed will be based on the use of a lead sulfide detector, tungsten source and mechanical modulator, substantially the same as previously described. The optical and electronic systems will permit a range of six miles.

The development of the electronic system is quite straight forward. There remains one basic problem to be solved, that being the use of transistors versus tubes in this application. We are investigating transistors at this time. A satisfactory investigation of transistors requires some time and by necessity must be carried into the developmental phase of the work. It is pointed out that we have already proposed to develop tube circuitry and modify for transistors should this be desirable in the course of future work.

The system will provide wide searchlight and receiver beams for searching and narrow beams for communication.

The estimated weight is as follows:

Optical System and Modulator	5 lbs.
Electrical and Electronics System	2 lbs.
Power System, Engine plus Generator	4 lbs.
Carrying Case plus Tripod	3 lbs.
Miscellaneous Mechanical Hardware	1 lb.
Total	15 lbs.

Cubical displacement is not as easy to forecast in this phase of the work since only very rudimentary estimates of the system layout can be made. However, a fairly good estimate is a case of approximately 18" x 12" x 8".

All components purchased will be of the best commercial construction, and fabricated parts will be of suitable material constructed according to the best possible engineering design.

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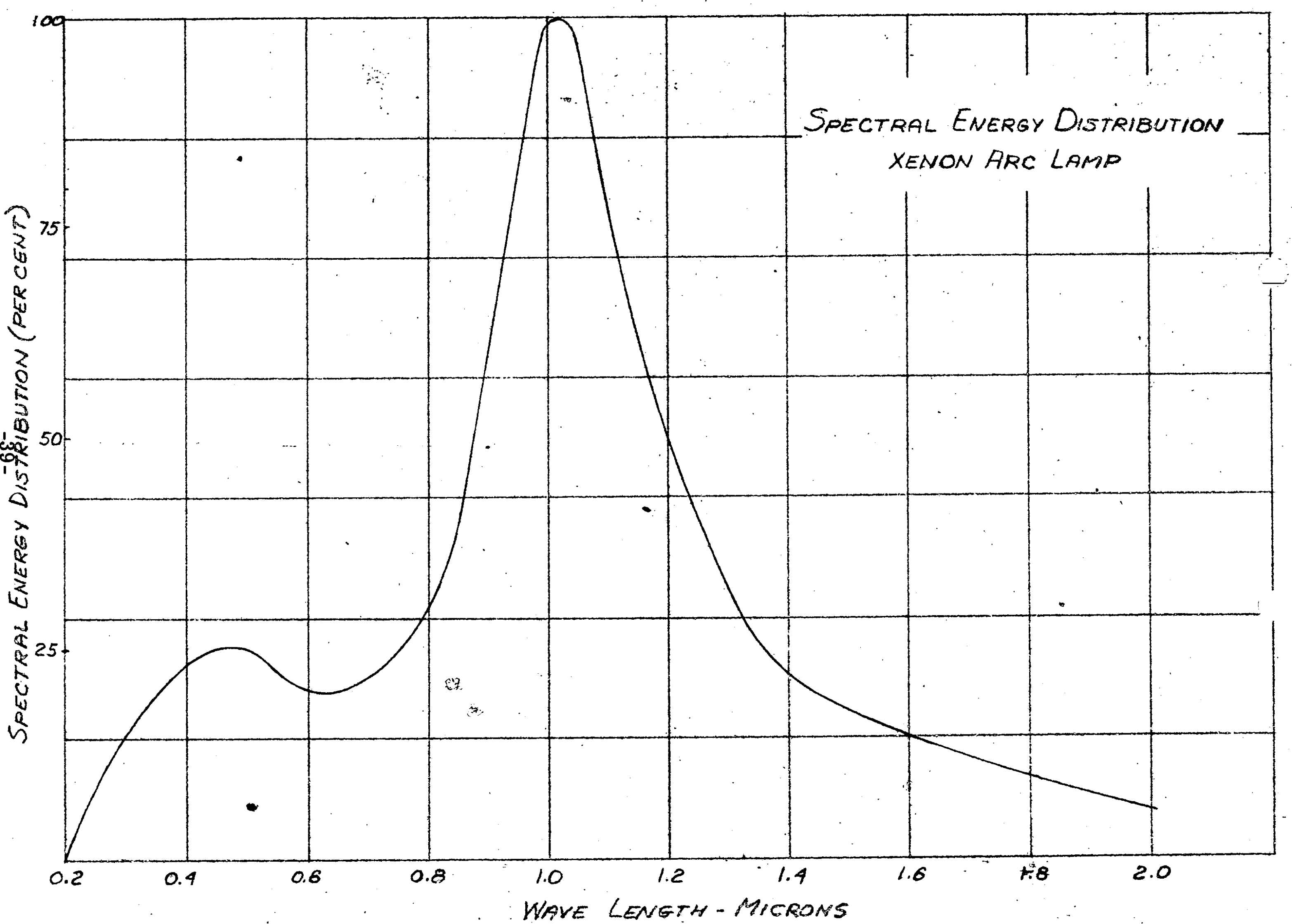
APPENDIX I

CURVES


SPECTRAL ENERGY DISTRIBUTION
XENON ARC LAMP
100
75
50
25
SPECTRAL ENERGY DISTRIBUTION (PER CENT)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
WAVE LENGTH - MICRONS

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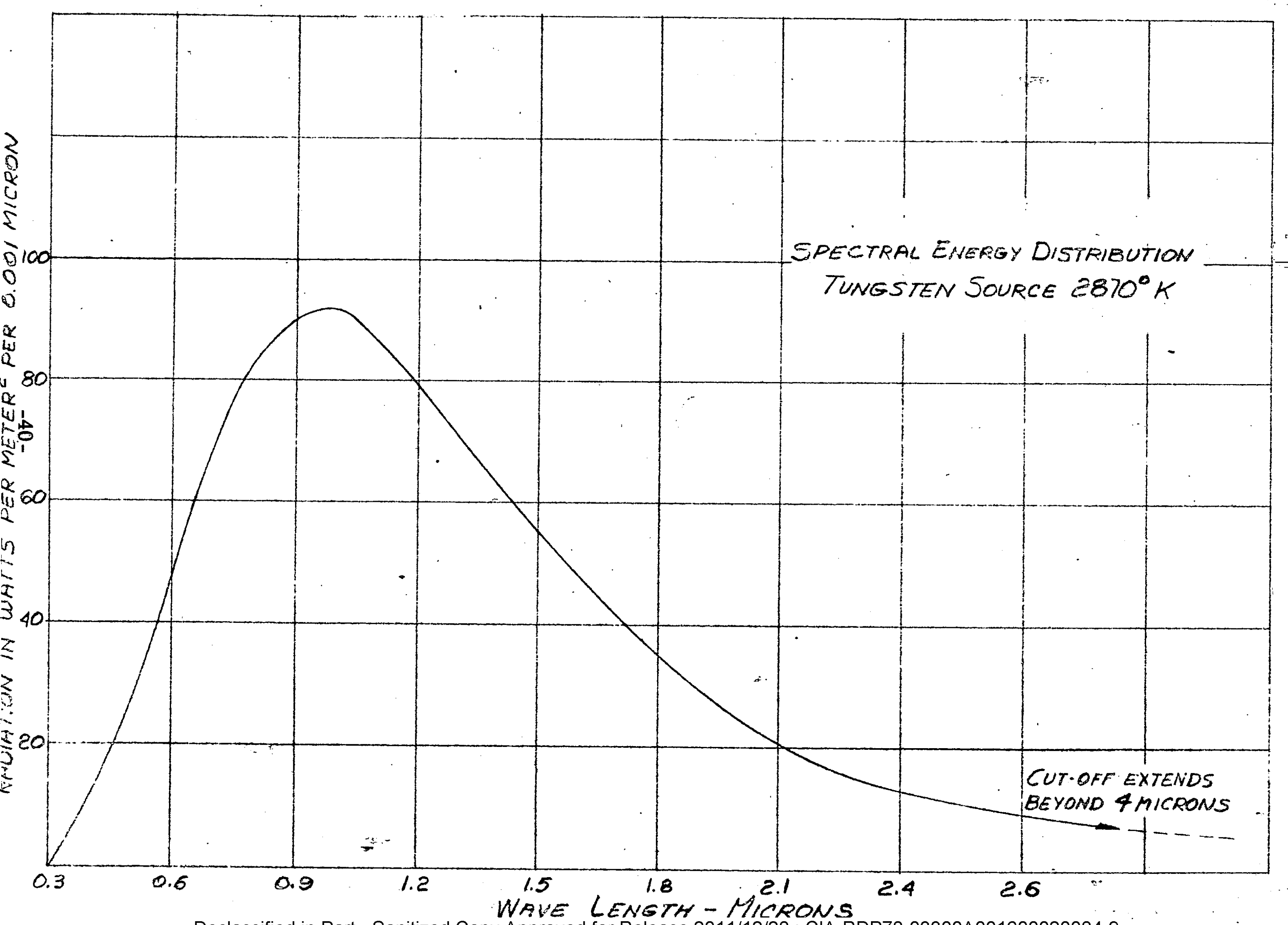

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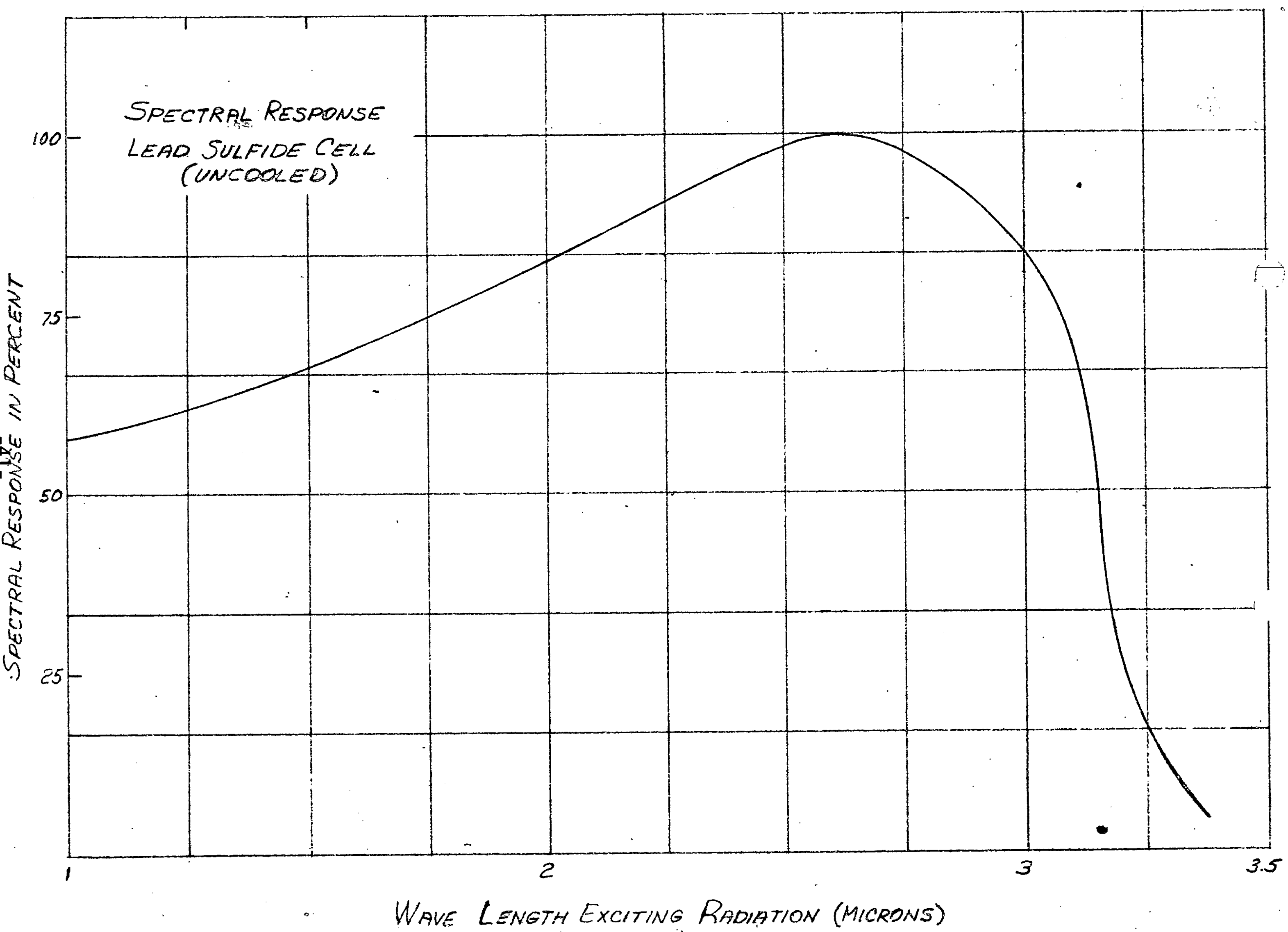

FIGURE 3

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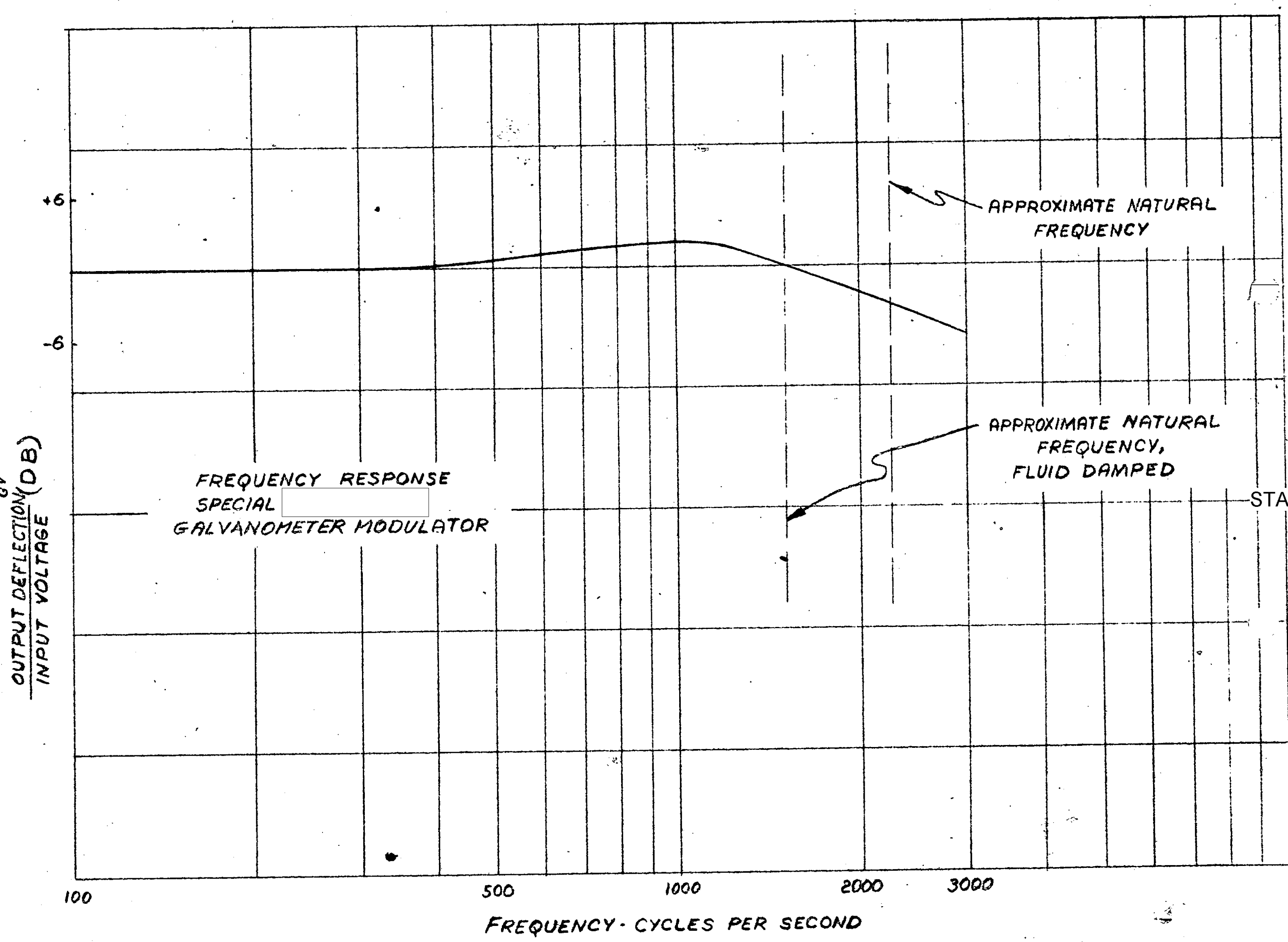

STAT

FIGURE 4

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APPENDIX II

FIGURES

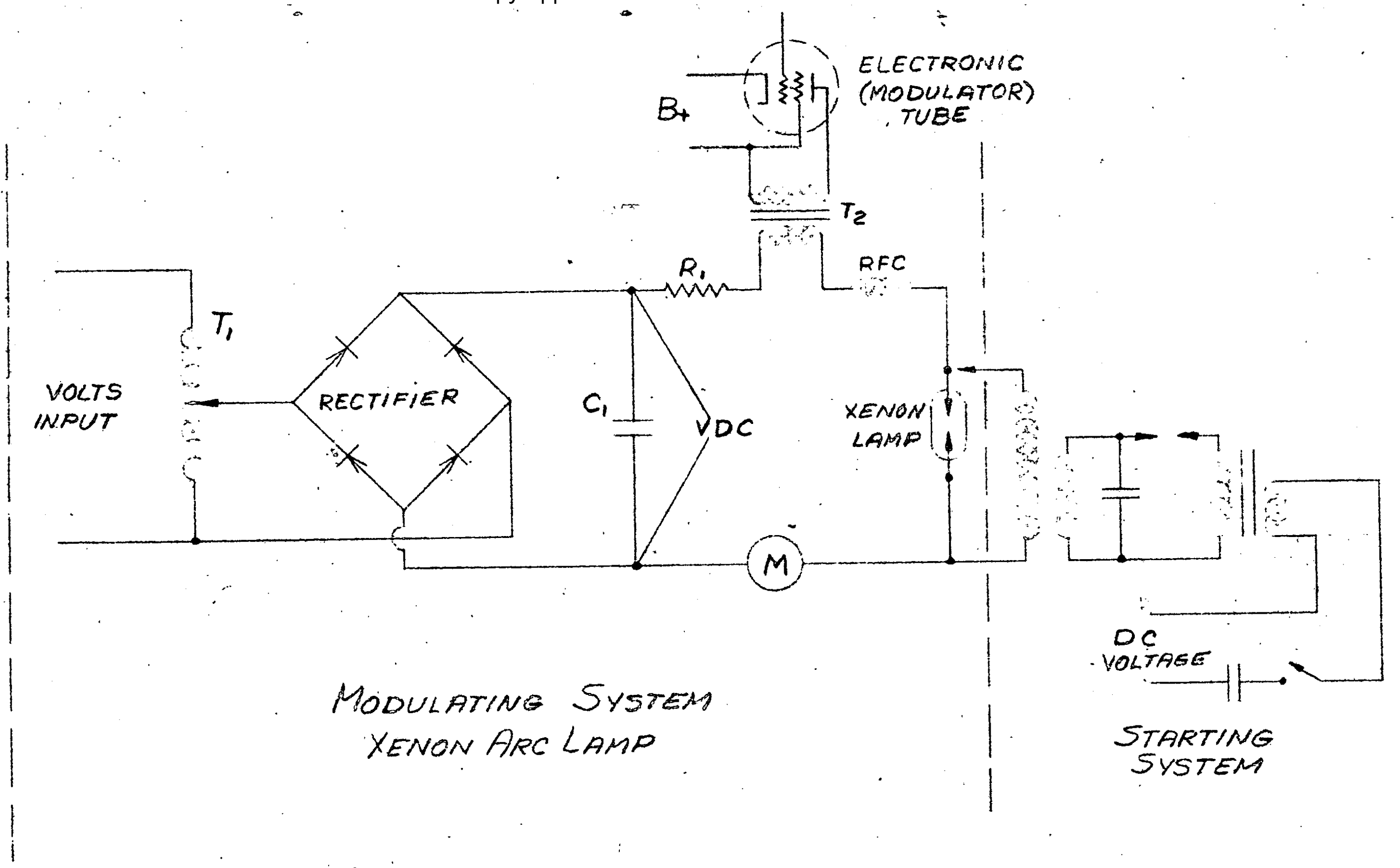

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FIGURE 5

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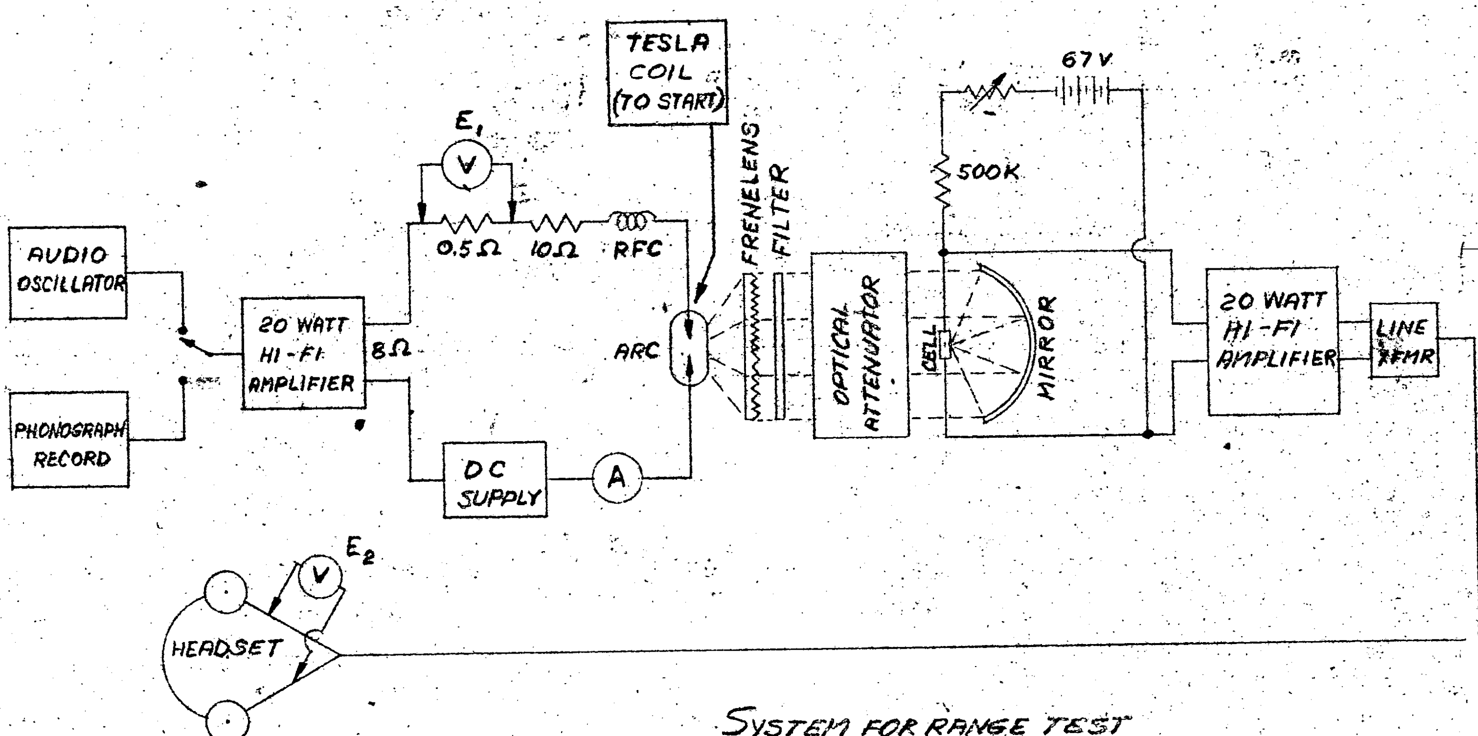

SYSTEM FOR RANGE TEST
ELECTRONICALLY MODULATED
XENON ARC
MODULATION 75%

FIGURE 6

BES 8-20-54

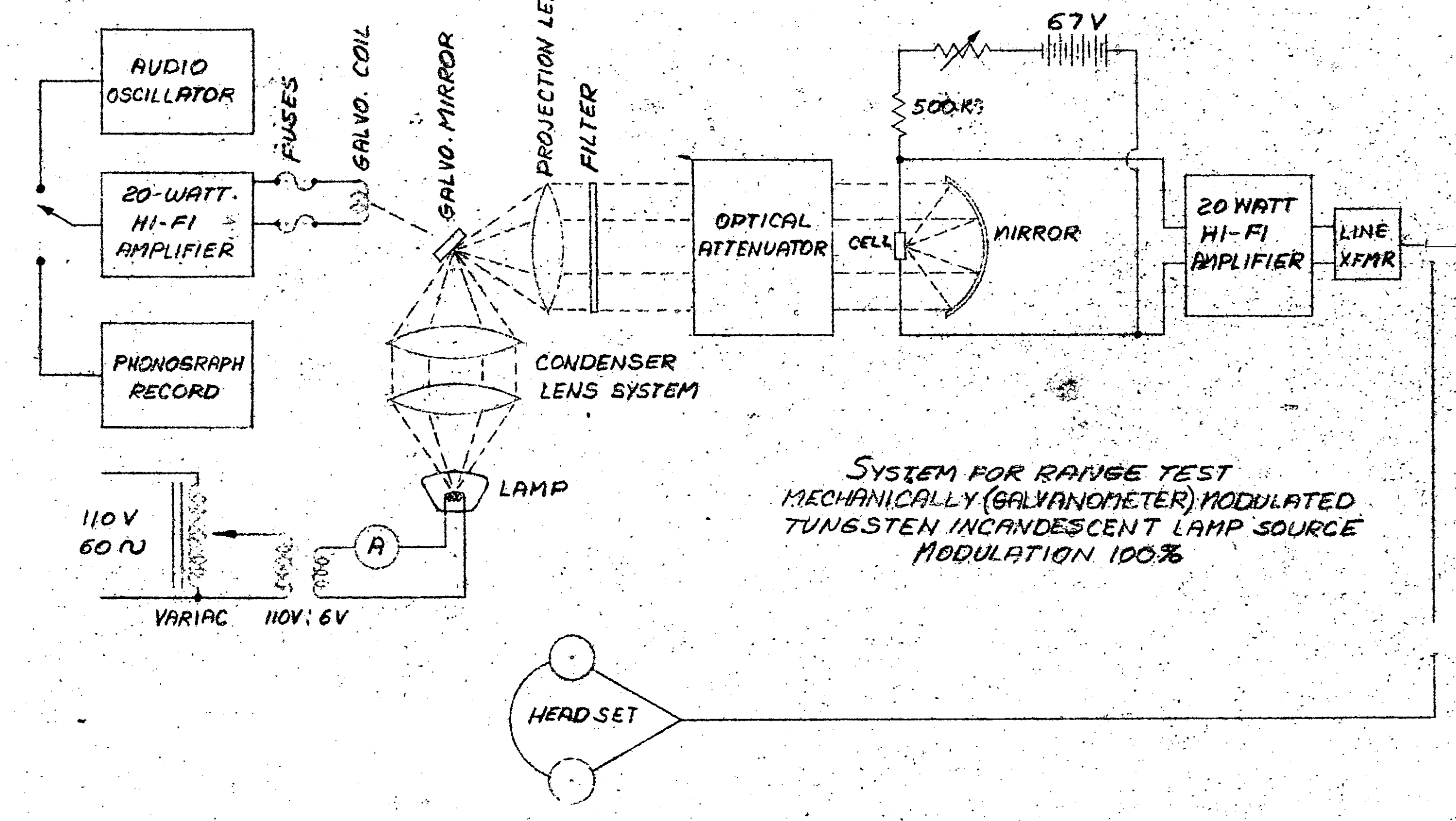

FIGURE 7

FES 8-20-54

APPENDIX III

TABLES

TABLE NO. 1

FREQUENCY RESPONSE (XENON ARC SYSTEM)

Frequency	E_2 (Out-put) Volts
300	1.00
600	0.56
1200	0.22
2400	0.075
3000	0.060

Conditions of Test:

Arc Current	1.2 amperes
E_1 (const.)	0.325 volts r.m.s.
Modulation	75%
Range	Equivalent 6 miles (average clear weather)
Noise	40 m.v. (approximately)

TABLE NO. 2

MECHANICAL MODULATOR (GALVANOMETER) CHARACTERISTICS

Undamped Natural Frequency 2250 C.P.S. (approx.)

Fluid Damped Natural Frequency 1550 C.P.S. (approx.)

Sensitivity; $+16^{o}$ Rotation within max. safe current Limits. (Stated in terms of linear deflection it is 3.5 in. deflection at a 12 in. optical arm)

Current Sensitivity 31 ma/in. (at 12 in. optical arm)

Mirror Size

Damping Factor 0.5 (approx.); Silicon Oil Damped

Mirror: Flat; 0.029 in. x 0.187 in.

Cover Glass; cylinder

TABLE NO. 3

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INTERNAL COMBUSTION ENGINE-GENERATOR DATA

Engine Data

Output: 0.2 H.P. minimum (when silenced with mufflers)

Speed: 11,000 to 13,000 r.p.m.

Operation:

10 hours without over-heating

Ignition: Glow Plug and "D" Cell

Rope starting

Air Cooled

Weight: 6 ounces (Bare Engine)

Generator Data

Output: 220 volts; 100 ma

6 volts; 9 amperes

Frequency: 800 cycles; Maximum speed 15,000 r.p.m.

No. Poles: 8; Wt. 1.5 lbs.

Total volume required for engine, generator and muffler approximately 175 cu. in.

Total weight including muffler and acoustical shielding: 4 to 5 pounds.

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